REMARKS

A substitute specification, complying with 37 C.F.R. §§ 1.52 (a) and (b), is attached herewith along with a copy showing the changes to the original specification as requested by the Examiner under 37 C.F.R. § 1.125 (Office Action, dated February 17, 2004, page 2, lines 8-15). Of note, the definition of "internal cell" in paragraph [0038] has been revised to include cells "wholly in a region outside of the boundary" in addition to cells "wholly in the interior of the "boundary" as supported by Figure 4 as originally filed. The instant substitute specification includes no new matter.

The drawings have been amended to label various sub-cells illustrated in Figures 2 and 4, and to add the character reference "1" to Figure 4 relating to the "object 1" described on page 7, line 2, of the specification as originally filed. Figure 7A has been labeled "prior art." No new matter has been added to the present application by these drawing amendments.

Claims 1-6 have been amended and add new claims 7-19 added. Claims 1-6 have been amended to improve grammar, punctuation, format, and to remove character references, all of which have no limiting effect on the scope of these claims. Claim 1 has been further amended to particularly point out and distinctly claim that the Octree division step is --by modified Octree division-- as described on page 9, line 18, to page 11, line 3, of the specification as originally filed. Claim 2 has been amended to particularly point out and distinctly claim that the "internal cell" is "located in the interior or the outside region of the object" as supported by Figure 4 of the application as originally filed.

New claims 7-19 have been added. Specifically, new claims 7-12 correspond to the

subject matter of claims 1-6, respectively, but re-written in language that does not invoke "step-plus-function" under 35 U.S.C. § 112, sixth paragraph. New claims 13 and 14 recite recursive repeats of the modified Octree division as supported on page 5, line 9, to page 7, line 16, and Figures 1 and 2 of the application as originally filed.

New claims 15-17 recite subject matter similar to new claims 10-12, respectively, but are dependent upon different claims. New claim 18 depends upon claim 17 and further recites the step of "acquiring cut points" as supported on page 10, lines 7-14, of the specification as originally filed. New claim 19 depends upon claim 18 and further recites the step of "expressing corner points by cut points possessed by adjacent boundary cells" as supported on page 11, lines 4-12, of the specification as originally filed.

The present amendments to the specification, drawings and claims adds no new matter to the instant application.

The Invention

The present invention pertains broadly to a method of storing substantial data integrating shape and physical properties such as would be used to store substantial data integrating shape and physical properties of an object so that the data can be stored in a small storage capacity. In particular, in a first embodiment in accordance with the present invention, a method of storing substantial data integrating shape and physical properties is provided that includes the steps of: (a) an external data input step (A) for inputting external data consisting of boundary data of an object; (b) an Octree division step (B) for dividing, by modified Octree division, the external data into cubical divided cells with boundary surfaces

orthogonal to each other; and (c) a cell data storage step (C) for storing the values of physical properties for each of the cells.

In accordance with a second embodiment of the present invention, a method of storing substantial data integrating shape and physical properties is provided that includes the following steps: (a) inputting to a computer external data consisting of boundary data of an object; (b) dividing, by modified Octree division, the external data into cubical first cells with boundary surfaces orthogonal to each other; and (c) storing the values of physical properties for each of the first cells.

Various other embodiments in accordance with the present invention are recited in the dependant claims. An advantage of the various embodiments, in accordance with the present invention, is that a method of storing substantial data integrating shape and physical properties is provided that more efficiently stores substantial data so that smaller storage capacities can be utilized during CAD and simulation operations. Furthermore, the methods in accordance with the present invention actually allow for the integration of CAD and simulation operations because the modified Octree division makes it possible to manage information related to both procedures.

The Rejections

Claims 3 and 4 stand rejected under 35 U.S.C. § 112, second paragraph, as indefinite.

Claims 1-5 stand rejected under 35 U.S.C. § 103(a) as unpatentable over the Kela reference ("Hierarchical octree approximations for boundary representation-based geometric models," 1989) in view of Shu et al. (U.S. Patent 6,075,538). Claim 6 stands rejected under

35 U.S.C. § 103(a) as unpatentable over the combination of the Kela reference and the Shu Patent, and further in view of Dundorf (U.S. Patent 5,197,013).

Applicants respectfully traverse the rejection and request reconsideration of the instant application for the following reasons.

Applicants' Arguments

Applicants assert that claims 1-19 are now in compliance with 35 U.S.C. § 112.

103 Rejections

The courts have held that to reject claimed subject matter in view of a combination of prior art references, a proper analysis under 35 U.S.C. § 103 must show that (a) the prior art would have suggested to those of ordinary skill in the art that they should make the claimed composition or device, (b) the prior art reveals that in so making, one of ordinary skill would have a reasonable expectation of success, and (c) both the suggestion and the reasonable expectation of success is found in the prior art and not in applicant's disclosure. In re Vaeck, 20 USPQ2d 1438, 1442 (Fed. Cir. 1991).

The Kela Reference

The Kela reference teaches "hierarchical octree approximations for boundary representation-based geometric models" that includes an octant classification procedure, as shown in Figure 1, using three types of octants: (i) "IN" octants, which are located wholly in the interior of the solid object, (ii) "OUT" octants, which are located wholly outside of the

solid object, and (iii) "NIO" octants, which are boundary octants being neither wholly inside or wholly outside of the solid object (Kela reference, p. 355, col. 2, lines 2-20).

As admitted by the Examiner, the Kela reference does not teach the step of "storing the values of physical properties" as recited in claims 1 and 7 (Office Action, dated February 17, 2004, page 4, lines 9-10). In addition, the Examiner admits that the Kela reference does not teach (a) "acquiring cut points" as recited in claims 3, 9 and 18 (Office Action, dated February 17, 2004, page 6, lines 5-11); (b) that each "internal cell has one kind of physical property value as an attribute, and each boundary cell has two kinds of physical property values relating respectively to the interior of the object and to regions outside of the object" as recited in claims 4, 10 and 15 (Office Action, dated February 17, 2004, page 6, lines 17-19); (c) that the "physical values consist of constant values which do not change by simulation, and variables which change as a result of simulation" as recited in claims 5, 11 and 16 (Office Action, dated February 17, 2004, page 8, lines 6-8), and (d) that the "external data" is "curved surface data for a three dimensional CAD or CG tool" as recited in claims 6, 12 and 17 (Office Action, dated February 17, 2004, page 9, lines 7-8).

In addition, Applicants assert that the Kela reference teaches a conventional Octree division method, and neither teaches nor suggests the "modified Octree division" recited in claims 1 and 7 in accordance with the present invention. The Examiner's attention is directed to Figures 7A and 7B of the present application, which illustrate the difference between conventional Octree division (see Figure 7A) and modified Octree division (see Figure 7B). Applicants' "modified Octree division" is fully described on page 9, line 25, to page 10, line 14, of the specification as originally filed.

Furthermore, the Kela reference teaches classifying each octant as either "IN," "OUT," or "NIO" (boundary), which is different from the presently claimed invention. As recited in claims 2, 8 and 13 of the present invention, each "cell is classified as either an internal cell...or a boundary cell." In other words, the presently claimed invention as recited in claims 2, 8 and 13 is limited to classifying only two types of cells (i.e., internal or boundary). A person skilled in the art would instantly recognize that the computational algorithm taught by the Kela reference would be inoperational if limited to only two of the three octant classifications. Therefore, there is nothing in the Kela reference that reasonably teaches, or even suggests, a "method of storing substantial data integrating shape an physical properties" that would classify "cells" as either "internal" or "boundary" as recited in claims 2, 8 and 13 of the present invention.

In view of all of the apparent deficiencies of the Kela reference outlined above, the Kela reference can neither anticipate, nor render obvious, the subject matter of claims 1-19 of the present invention.

<u>The Shu Patent</u>

The Shu Patent teaches a "time and space efficient data structure and method and apparatus for using the same for surface rendering," which utilizes conventional octrees, preferably summarized information octrees (SIOs), (col. 5, lines 46-65). It is noted that the Shu Patent actually teaches 2-dimensional quadtrees, and merely suggests application to 3-dimensional SIO (col. 5, line 66, to col. 6, line 8). The Shu Patent teaches that in 3-dimensions, the volume data set for a 3-dimensional space scalar field would be partitioned

into NxNxN identical cubes, with each cube having 6 faces and 8 voxels (col. 6, lines 18-34). Each "cube" is also referred to as a "cell," and each cell is classified according to its density value as either a 0-cell, a 1-cell, or an S-cell (col. 1, line 25, to col. 2, line 27). Specifically, Shu defines cells as follows: an 0-cell has, for each of the 8 voxels, a density value less than a threshold value t; a 1-cell has, for each of the 8 voxels, a density value more than the threshold value t; and an S-cell has some voxels with a density value less than t and some voxels with a density value greater than t (col. 2, lines 14-27).

There is nothing in the Shu Patent that teaches, or even suggests, the "modified Octree division" recited in claims 1 and 7 of the present invention. Furthermore, the Shu Patent teaches a three-way classification scheme (i.e., 0-cell, 1-cell, S-cell) for each cell of the volume data set, which is similar to the three-way classification scheme (i.e., IN, OUT, NIO) taught by the Kela reference. Therefore, the Shu Patent fails to teach the two-way classification of "cells" as either "internal" or "boundary" as recited in claims 2, 8 and 13 of the present invention for the same reasons that the Kela reference fails to teach this limitation.

The Dundorf Patent

The Dundorf Patent teaches a "method of forming a carved sign using an axially rotating carving tool," which relates to producing a carved sign using a CAD/CAM computer (col. 7, lines 1-10). The Dundorf Patent teaches an application of the parametric cubic curve to geometrical and graphical modeling (col. 9, line 19, to col. 12, line 55), and suggests that conventional Octree encoding can be used as a data structure for representing a three-

dimensional object (col. 17, lines 18-40). However, the Dundorf Patent does not teach, or even suggest, the "modified Octree division" recited in claims 1 and 7 of the present invention, and the two-way classification of "cells" as either "internal" or "boundary" as recited in claims 2, 8 and 13 of the present invention.

Applicants also note that none of the prior art references teach, or even suggest, the step of "acquiring cut points" as recited in new claim 18 and the step of "expressing corner points by by cut points possessed by adjacent boundary cells" as recited in new claim 19.

Summary of the Prior Art

It is apparent that neither the Kela reference, the Shu Patent, nor the Dundorf Patent teach, or even suggest, the "modified Octree division" recited in claims 1 and 7 of the present invention, and the two-way classification of "cells" as either "internal" or "boundary" as recited in claims 2, 8 and 13 of the present invention. For this reason alone, no combination of the Kela reference, the Shu Patent and the Dundorf Patent can properly sustain a rejection under 35 U.S.C. § 103(a) of independent claims 1 and 7, and dependent claims 2, 8 and 13, of the present invention.

The Examiner's Unsubstantiated Assertions

First, with respect to claim 3, the Examiner asserts that Applicants' Specification discloses on page 3 that '"Each boundary cell can be strictly or approximately replaced by cut points." (February 17th Office Action, page 6, lines 8-11).' Applicants believe that there is no such admission on page 3 of the originally filed specification of the present application.

Applicants point out that the original specification actually describes further Octree division of boundary cells until a sufficient number of cut points are acquired to reconstruct boundary shape elements (Original specification, page 10, lines 7-10). In addition, the Examiner appears to be using Applicants' specification as if it were prior art, which it is not. Applicants remind the Examiner that only teachings grounded in the prior art, and not the Applicants' disclosure, can be used against Applicants' claims. In re Vaeck, 20 USPQ2d at 1442.

Second, with respect to claim 5, the Examiner admits that the Kela reference does not teach that the "physical property values consist of constant values which do not change by simulation, and variables which change as a result of simulation" (February 17th Office Action, page 8, lines 5-7). The Examiner states that it is well known in the art that stored values would be either constant values or variable values, and then draws the conclusion that it would be obvious to provide physical property values that are constant values and variable values (February 17th Office Action, page 8, lines 8-16).

The Federal Circuit has ruled that subjective belief and unknown authority is an improper basis for establishing motivation, and cannot be used in establishing unpatentability. In re Lee, 61 U.S.P.Q.2d 1430, 1434 (Fed. Cir. 2002). In fact, the Federal Circuit has ruled that the Administrative Procedure Act creates a statutory duty for the U.S. Patent & Trademark Office to provide evidence in support of unpatentability determinations. In re Lee, 61 U.S.P.Q.2d at 1433.

In view of the rulings of the Federal Circuit, the Examiner's subjective belief, in the absence of evidence, is insufficient to support a rejection of claim 5. Applicants respectfully

request that the Examiner provide a reference to support that "physical property values consist of constant values...and variables...," as recited in claims 5, 11 and 16 of the present application, is taught by the prior art. In the absence of such a prior art teaching, the Examiner's rejection of claims 5, 11 and 16 is untenable and should be withdrawn.

Conclusion

Claims 1-19 as amended are now in compliance with 35 U.S.C. § 112. Furthermore, the rejection under 35 U.S.C. § 103 standing against the claims is untenable and should be withdrawn because neither the Kela reference, the Shu Patent nor the Dundorf Patent teach, or even suggest, the "modified Octree division" recited in independent claims 1 and 7. All of the remaining claims depend, either directly or indirectly, upon claims 1 and 7 and are likewise allowable.

For all of the above reasons, claims 1-19 are in condition for allowance and a prompt notice of allowance is earnestly solicited. Questions are welcomed by the below-signed attorney for applicants.

Respectfully submitted,

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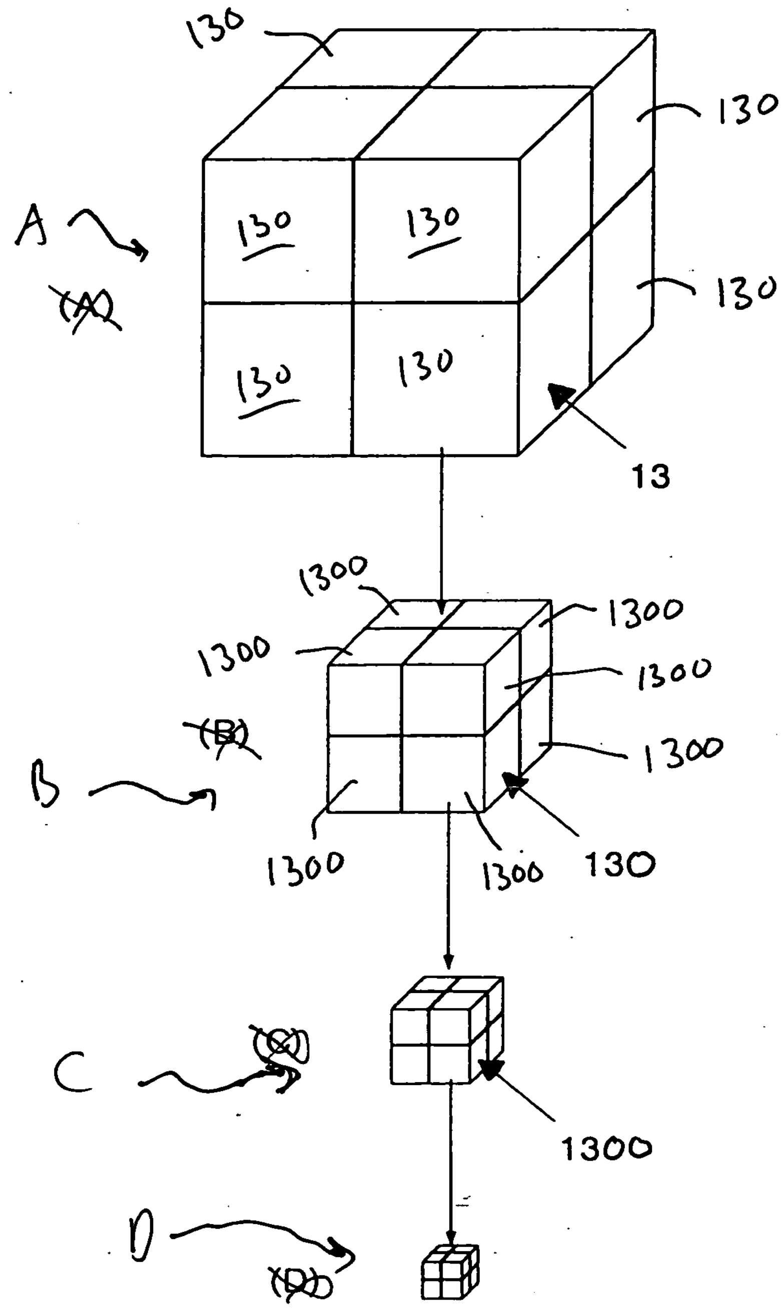
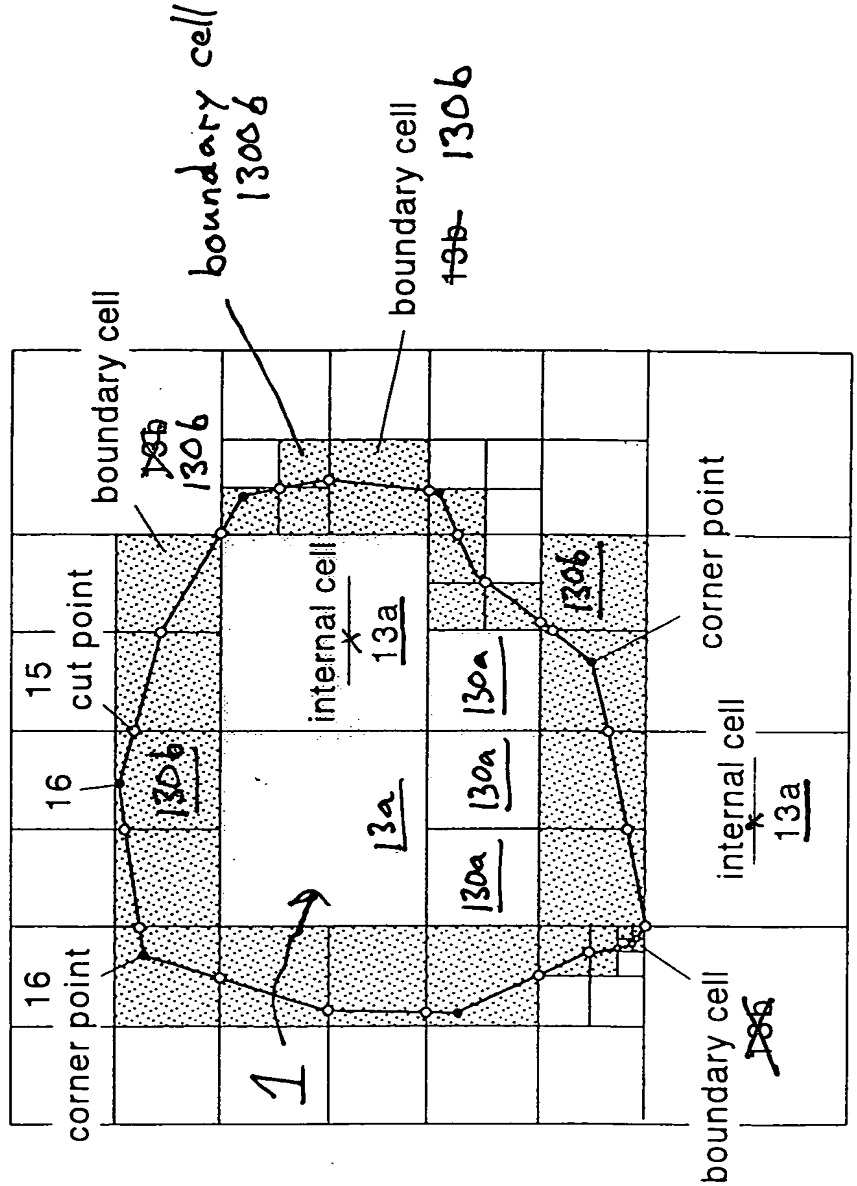
ANNOTATED MARKED-UP DRAWING

Fig.2



ANNOTATED MARKED-UP DRAWING

Fig.4



ANNOTATED MARKED-UP DRAWING

Fig.7A

Prior Art

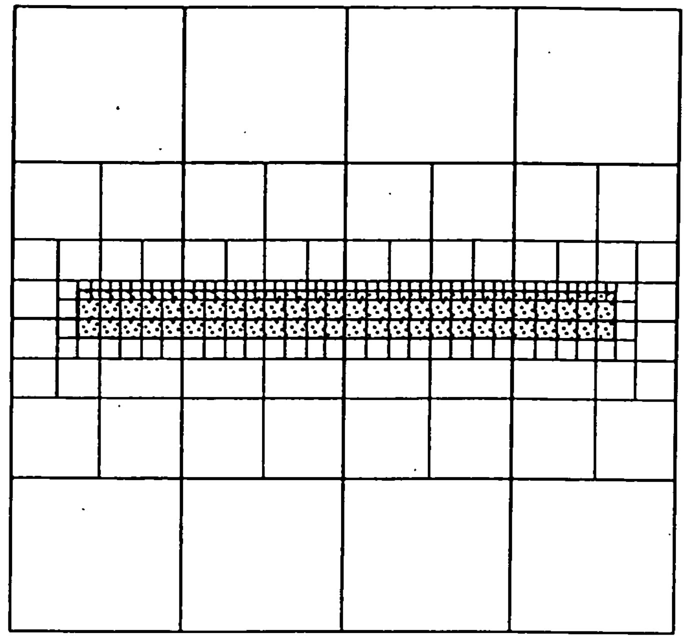
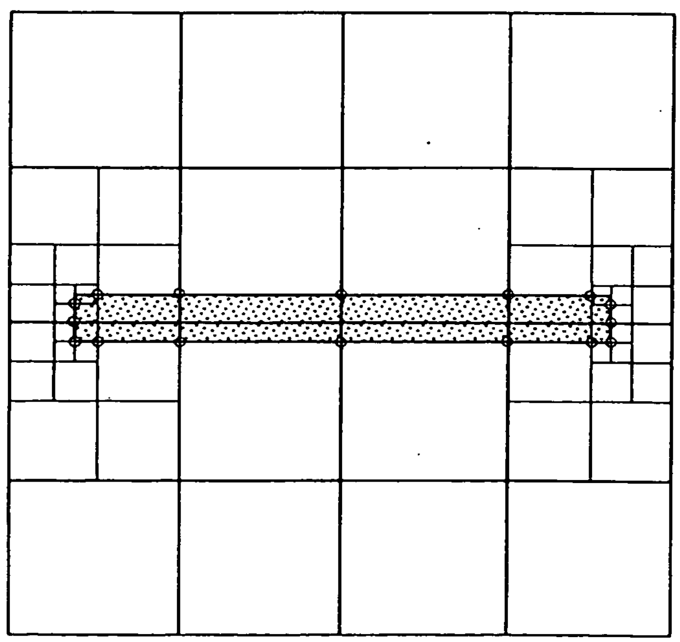


Fig.7B



STORAGE METHOD OF SUBSTANTIAL DATA INTEGRATING SHAPE AND PHYSICAL PROPERTIES

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] ~~——~~The present invention relates to a method of storing substantial data that~~which~~ can store substantial data pertaining to integrating shape and physical properties in a small storage capacity so as to integrate CAD and simulation processes.

Description of the Related Art

[0002] In the field~~location~~ of high technology research and development, due to~~with~~ increases in sophistication and complexity, an enormous amount of trial and error has been necessary~~,~~ which~~thereby~~ increases~~ing~~ risk of error in the course of technology development. For a~~our~~ country aiming at developing~~a~~ science and technology~~-based country~~, it is very important to minimize these development risks and to achieve increased sophistication with~~and~~ greater efficiency of the development process.

[0003] At present, in the field~~location~~ of computer research and development, simulation means, such as ~~CAD~~ ~~(~~Computer Aided Design (abbreviated CAD), ~~CAM (~~Computer Aided Manufacturing (abbreviated CAM), ~~CAE (~~Computer Aided Engineering (abbreviated CAE), and ~~CAT (~~Computer Aided Testing (abbreviated CAT), are~~is~~ used for simulating design,

work, analysis, and test situations, respectively. On the other hand~~Further~~, less commonly used simulation means include~~due to the benefits arising from the present invention,~~ C-Simulation (Corporation Simulation) of continuous simulation, A-CAM (Advanced CAM) considering work process, and D-fabrication (Deterministic fabrication) providing ultimate accuracy~~y are to be in common use~~.

[0004] For~~In the~~ conventional simulation means such as listed~~described~~ above, ~~an~~ object data is stored by ~~CSG~~ ~~(~~Constructive Solid Geometry (abbreviated CSG) or by ~~B-rep~~ ~~(~~Boundary Representation (abbreviated B-rep). However, because CSG stores the whole data corresponding to~~of~~ an object as an assembly of fine solid models, the data required is massive~~heavy~~. Thus, ~~so that~~ when installing simulation means via~~of~~ software, an enormous amount of data must be handled~~treated~~ by the computing system, thereby~~us~~ resulting in a time problem ~~that~~ even with the use of a high speed computer. Such large amounts of data~~would~~ take much time for analysis.

[0005] In the alternative~~Further~~, B-rep methods represents ~~an~~ object data by boundaries;~~,~~ ~~and~~ therefore, less~~the~~ data is required which is ~~light and~~ less burdensome on the computing system~~in amount~~. However, B-rep has a limitation in~~problem~~ that it is not suitable for deformation analysis~~,~~ because the interior of the boundary plane must be~~is~~ treated uniformly.

[0006] Furthermore, conventional~~such~~ data storage means divides an object into meshes suitable for analysis, and then applies a finite-element method to these~~m~~ meshes, as is required in heat and fluid analysis, large deformation analysis of solids, ~~and these~~ continuous analyses and the like. Consequently~~As a result~~, although the results of the analyses can be displayed, it is difficult to integrate CAD and simulation methods so~~, and thus~~ there is a problem in that each process of design, analysis, work, assembly and testing can not be managed under the same common data construct.

[0007] In other words, in view of the current state of Solid / Surface-CAD (hereinafter, referred to as "S-CAD"), there have been the following problems:~~.~~

(1) Data can not be used commonly in different software~~s~~ applications because the technology does not provide for~~as it is weak for the~~ data conversion;~~.~~

(2) S-CAD~~It~~ can not be used for simulation directly because~~. As~~ it does not have internal information;~~,~~ thus, the generation of meshes is required; and~~.~~

(3) S-CAD~~It~~ can not be used to study machining by CAM because S-CAD addresses~~it has~~ only final shapes.

Furthermore, S-CAD~~it~~ has the following problems with respect to~~in~~ machining applications:~~.~~

(1) S-CAD~~It~~ can not represent work processes. It is a method insufficient to support ~~for~~ rough machining and process design applications;~~.~~

(2) S-CAD~~It~~ is not suited to new machining techniques such as laser beam machining and high technology machining. Conventional S-CAD~~It~~ is suited ~~to~~ only to cutting applications, and has poor accuracy with regards to~~in~~ numerical values;~~.~~ and

(3) S-CAD~~It~~ does not allow the selection of machining techniques~~ itself for~~ when working with a complex material having different properties therein.

SUMMARY OF THE INVENTION

[0008] The present invention endeavors to~~has been invented for~~ overcome~~ing~~ these problems. That is, an object of the present invention is to provide a method of storing substantial data, wherein~~ich~~ the method enables storing substantial data integrating shape and physical properties in a small storage capacity, thereby allowing the management~~ing~~ of shape information, structure information, physical-property information, and history of matter information in an integrated manner. The method of storing substantial data, in accordance with the present invention, ~~and~~ also allows the management~~ing~~ of data associated with a series of processes from design processes to work processes, assembly processes, test processes and evaluation processes using the same data, thus allowing integratio~~n~~n~~g~~ of CAD and simulation methods.

[0009] The present invention provides a method of storing substantial data integrating shape and physical properties, ~~characterized by~~ comprising (a) an external data input step

(A) for inputting external data 12 consisting of boundary data of an object (1);~~,~~ (b) an Octree division step (B) for dividing, by Octree division, the external data ~~(12)~~ into cubical cells ~~(13~~,~~)~~ which boundary surfaces are orthogonal to each other;~~,~~ and (c) a cell data storage step (C) for storing the values of various physical properties for each of the cells.

[0010] According to a preferred embodiment of the present invention, in the~~said~~ Octree division step (B), each of the divided cells is classified as one of the following: (a)~~to~~ internal cells ~~(13a)~~ located in the interior of the object or in the region outside of the object, and (b) boundary cells ~~(13b)~~ including boundary surfaces.

[0011] Moreover, the~~said~~ boundary cells ~~(13b)~~ are~~is~~ re-divided by ~~the~~ Octree division until acquiring cut points sufficient~~enough~~ to enable the reconstruction of boundary shape elements that make~~ing~~ up the boundary surfaces included in the external data.

[0012] Furthermore, each~~said~~ internal cell ~~(13a)~~ has one kind of physical property value as its attribute, whereas~~and~~ each~~the~~ boundary cell ~~(13b)~~ has two kinds of physical property values corresponding to~~of~~ the interior and exterior (i.e., outside) of the solid.

[0013] Furthermore, the~~said~~ physical property values

consist of constant values, which do not change during~~by~~ simulation, and variables, which do change as a result of simulation.

[0014] Still further, the external data ~~(12)~~ is provided in the following forms: polygon data representing a polyhedron, a tetrahedron or a hexahedron element for a finite-element method;~~,~~ curved surface data for a three dimensional CAD or CG tool application;~~,~~ or data for representing the surface of another solid provided as information comprising partial planes and curved surfaces.

[0015] According to the method of storing substantial data of the present invention described above, ~~the~~ external data ~~(12)~~ can be stored into a small storage space in the form of a~~capacity as the~~ hierarchy of cubical cells. These cubical storage~~, which~~ cells are obtained by dividing the external data of the object ~~(12)~~ into the cubical cells with orthogonal boundary surfaces by using Octree division. Also, as each cell stores various physical properties as its attributes, it becomes~~is~~ possible to manage shape information, structure information, physical-property information, and history of matter information in an integrated manner. It ~~,~~ ~~and~~ also becomes possible to manage data associated with a series of processes from design processes to work processes, assembly processes, test processes and evaluation processes using~~under~~ the same data, thus allowing the integration of CAD and simulation processes.

[0016] In other words~~That is~~, because the method of storing substantial data of the present invention can store and represent not only object data, but also physical attributes as well, it is possible to construct advanced simulation technology and interface technology between human and matter, using the hierarchical data utilized in the present invention as the platform.

[0017] Another object of the present invention is to provide a method of storing substantial data that permits the common usage of C-Simulation (Corporation Simulation) of continuous simulation, A-CAM (Advanced CAM) considering work process, and D-fabrication (Deterministic fabrication) with improved accuracy.

[0018] Other objects and advantageous characteristics of the present invention will become apparent from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a flow chart showing steps of a method of storing substantial data in accordance with one embodiment of~~according to~~ the present invention.

[0020] FIG. 2 is a diagrammatic representation of the hierarchical data structure according to the present invention.

[0021] FIG. 3 shows examples of interpolating curved-surface in accordance with the present invention.

[0022] FIG. 4 is a schematic diagram showing the Octree division method according to the present invention (in two dimensions).

[0023] FIG. 5 is a schematic diagram showing attributes of each cell in accordance with~~of~~ the present invention.

[0024] FIG. 6 is a schematic Venn diagram~~schematically~~ showing~~s~~ the relationship between V-CAD and V-CAD data according to the present invention and ~~the~~ other simulation means.

[0025] FIGs. 7A and 7B are~~is a~~ schematic diagrams showing the comparison of the division method according to the present invention (referred to as "modified Octree" division) in FIG. 7B with the conventional Octree division of FIG. 7A.

DESCRIPTION OF PREFERRED EMBODIMENT

[0026] Hereinafter, a~~n~~ preferred embodiment of the present invention will be described with reference to the drawings.

[0027] FIG. 1 shows a flow chart illustrating steps of a method of storing substantial data according to the present

invention. The method of storing substantial data in accordance with the present invention comprises the following steps: (a) an external data input step (A);~~,~~ (b) an Octree division step (B);~~,~~ and (c) a cell data storage step(C). As shown in FIG. 1, steps (A), (B) and (C) are sub-steps of step S2.

[0028] In the external data input step (A), external data 12, consisting of boundary data of the object 1, is input to a computer. The external data 12 is gathered~~ined~~ in an external data acquisition step S1. The computer performing~~have stored~~ the storing substantial data method of the present invention is provided with the method stored therein. In the Octree division step (B), the external data 12 is divided by modified Octree division into cubical cells 13 whose boundary surfaces are orthogonal to each other as shown in FIG. 7B. In the cell data storage step (C), the values of various physical properties for each of the cubical cells 13 are stored. H~~Further, h~~ereinafter, the hierarchical data stored in accordance with~~ing to~~ the method of the present invention will be referred to as "V-CAD data", and the design or simulation using such V-CAD data will be referred to as "Volume CAD" or "V-CAD".

[0029] As shown in FIG. 1, ~~in a step S2~~ corresponding to the method of storing substantial data in accordance with~~of~~ the present invention, in step S2, the modified Octree division sub-step (B) may be repeated as required.

Furthermore, in ~~a~~ step S3, simulation, such as design simulation, analysis simulation, work simulation, assembly simulation, and test simulation, are performed using V-CAD data 14. T~~ and t~~he results of the simulation step S3 are preferably outputted to ~~a~~ output step S4, where the results are outputted ~~(~~as CAM or polygon data~~)~~.

[0030] The external data 12 gathered in the external data acquisition step S1 is externally inputted in external data input sub-step (A) a~~i~~s any of the following: (i) polygon data representing a polyhedron, a tetrahedron, or a hexahedron element used for a finite-element method;~~,~~ (ii) curved surface data used for a three dimensional CAD or CG tool;~~,~~ or (iii) data used for representing the surface of the other solids in the form of~~as~~ information comprising partial planes and curved surfaces.

[0031] In addition to such forms of data (also referreed to as "S-CAD data"), the external data 12 may take the form of~~may be~~ Volume data that also has~~having also~~ internal information such as (1) data directly input by a person using a~~by~~ V-CAD-specific interface (also referred to as a "V-interface"), (2) digitized surface data ~~of surface~~ such as that obtained by measuring instruments, sensors, and digitizers, (3) voxel data used for CT scanner, MRI, and general Volume rendering technologies.

[0032] FIG. 2 is a diagramm~~mm~~atic representation of the

hierarchical data structure according to the present invention. In the Octree division sub-step (B) described above, space division is performed by modified Octree division. Octree representation, (i.e., space division by Octree), divides a reference cube 13 containing an object into 8 cell regions 130, and recursively repeats this 8 cell region division process until the solid is~~will be~~ wholly contained in each of the cell regions, or not contained therein, as shown in (A), (B), (C), (D) of FIG. 2. In other words, Octree division takes the reference cube 13 and divides it into 8 cell regions 130, then takes each cell region 130 and further divides it into 8 sub-cell regions 1300, and then takes each sub-cell region 1300 and further divides it into 8 regions and so on until the solid is wholly contained, or not contained, by the divisions. This Octree division method can reduce the amount of data required to represent an object more greatly than ~~the~~ voxel representation.

[0033] Thus, a~~A~~ space region obtained by the ~~space~~ division of space based on Octree division is referred to as a cell~~13~~. So, cube 13 is divided into 8 cells 130, and each cell 130 is divided into 8 cells 1300, and so on. Each~~The~~ cell is a cube whose boundary planes are orthogonal to each other as shown in FIG 2. The hierarchical structure based on these cells uses~~,~~ the number of divisions to~~or resolution~~ represent~~s~~ regions occupied in space in order to achieve resolution. This hierarchical structure enables an~~the~~ object to be

represented in the whole space as the accumulation of cells of different ~~in~~ sizes.

[0034] In other words~~That is~~, using~~in~~ the Octree division step (B), the physical properties of the interior and boundaries of an object are transformed from the external data 12 into substantial data 14 (i.e., V-CAD data) ~~14~~ as described below. The boundary data, for example~~,~~ a plane, can be strictly reconstructed by 3 points included therein. In the alternative,~~Or~~ the boundary data can be chosen~~are~~ within a designated allowable difference such as a ~~(~~position difference, a tangential line difference, a normal difference, a curvature difference, and the threshold difference designated for connectivity with adjacent parts thereof~~)~~.

[0035] FIG. 3 shows examples of interpolating curved-surface, which is an example of choosing boundary data within a designated allowable difference. A special case of ~~the~~ interpolating curved-surface is the iso-surface used in Marching Cube methods. In accordance with~~According to~~ the present invention, the division process is repeated until a~~the~~ cell can be represented by a cut point on a ridge line, or until the cell~~it~~ satisfies normal, main curvature, and connectivity conditions. Examples MC1, MC2, MC5, MC8 and MC9 of iso-surfaces in the Marching Cube, shown in Fig.3, can be applied to the present invention.

[0036] Furthermore, only geometric eigen-amount (eigen-

value) is maintained~~kept~~ using strict representation for~~up to~~ quadratic surfaces, whereas~~and using~~ approximation by intra-cell curved surface based on a quadratic surface is used for free curved-surfaces.

[0037] FIG. 4 is a schematic diagram showing the division method according to the present invention in two dimensions. According to the present invention, in the Octree division step (B) described above, each of the divided cells 13, 130, 1300 is classified as either~~to~~ an internal cell such as 13a, 130a located in the interior of the object or as~~and~~ a boundary cell, such as 130b, 1300b, that includes~~ing~~ the boundary surfaces.

[0038] That is, the present invention uses a~~the~~ modified Octree for representing boundary cells such as 130b, 1300b, wherein a cell included wholly in the interior of the boundary or wholly in a region outside of the boundary is ~~comprised of~~ an internal cell, such as cells ~~(cube)~~ 13a, 130a, which are cubes of largest size. On the other hand, in accordance with the present invention,~~, and~~ a cell having boundary information from the external data 12 contained therein is ~~comprised of~~ a boundary cell such as cells 130b, 1300b. Each boundary cell, such as 130b, 1300b, can be strictly or approximately replaced by cut points 15 (shown by open circles in Figure 4) on twelve ridge lines in three dimensions, and on four ridge lines in two dimensions.

[0039] The boundary cells~~ 13b~~ are Octree-divided until cut points 15 are acquired sufficient~~enough~~ to reconstruct the boundary shape elements making up a boundary included in the external data 12. The boundary shape elements may be strictly reconstructed~~ strictly~~ for an analyzed curved surface such as a plane and quadratic surface, and approximately reconstructed for a boundary shape element represented by an~~the ~~other free curved-surface and a discrete point group.

[0040] For example, when reconstructing~~for~~ a line segment, space will be Octree divided until two points on the line segment become~~s~~ the cut points 15 on the ridge line. F~~, and f~~or a plane, space will be Octree divided until three points become~~will be~~ the cut points. Likewise, ~~and ~~for a quardratic line, Octree division of space is performed until three points become the cut points, and for a quadratic surface Octree division of space is performed until four points become the cut points, respectively. In the same manner, for each of polynominal surfaces and rational surfaces, when~~if~~ the representative formulas of the external data are already known, space is hierarchically Octree divided until a necessary and sufficient number of cut points and ridge lines of the cells are found within the defined range.

[0041] In other words~~That is~~, the reconstructed position ~~to be re-divided ~~is divided until a cell satisfies designated resolution on the boundary ~~(surface) ~~area (i.e., surface

area) or until the change rates of analysis results ~~the~~ values ~~of analysis results~~ (i.e., stress, distortion, pressure, flow rate, etc.) will be not greater~~higher~~ than designated threshold values.

[0042] F~~urther, f~~or the corner points 16 (shown by the blackened circles in Figure 4) of a boundary cell, for example 130b, including a plurality of boundary shape elements, the~~y~~ corner points are not divided more than necessary~~,~~ because their internal boundaries can be indirectly expressed as lines of boundary intersection, ~~of the boundaries~~ which are represented by the cut points 15 possessed by~~in the possession of~~ adjacent boundary-cells. These boundary-cells have sufficient cut-points for reconstruction, and are divided until they are completely traversed by the boundary elements.

[0043] Therefore, V-CAD data 14 includes the following:~~,~~ ~~as~~ information with respect to ~~of~~ the shapes stored in the interiors of the cells;~~,~~ characteristics for representing the position of the cells, the number of cellular divisions, or resolution, for representing the degree of detail ~~degree~~ in the hierarchy;~~,~~ a pointer for representing adjacent cells;~~,~~ the number and coordinate values of cut points;~~,~~ and normal and curvature information related to the applications.

[0044] In addition~~Further~~, as V-CAD data, the lowest layer in the hierarchy holds node information and the results

values ~~of results~~ in the manner of Euler. Furthermore, d~~How to d~~etermination of~~e~~ threshold (i.e., allowable differences) with respect to the position of boundaries, normal lines, continuity of tangential lines, and each continuity of curvatures, are~~is~~ defined so~~uch~~ that ~~minimal~~ resolution by~~in~~ re-dividing may be maximized as much~~as large~~ as possible.

[0045] FIG. 5 is a schematic diagram showing attributes of each cell in accordance with~~of~~ the present invention. An~~The~~ internal cell, such as cell 13a described above, has one kind of physical property value as its attribute, whereas a~~and the~~ boundary cell, such as cell 130b, has two kinds of physical properties which are related to~~of~~ the interior of the object and regions~~of~~ outside of the object.

[0046] In other words~~That is~~, although each cell is classified as either~~to~~ an internal cell or~~13a and~~ a boundary cell~~13b~~, and further each cell (whether an internal cell or a boundary cell)~~of them~~ includes two kinds of space cells (utilized for reconstructing fluid, using Euler methods) and shift deformation cells (utilized for reconstructing solid, using Lagrange methods). For V-CAD, only boundary cells 13b have two~~he~~ attribute values, one corresponding to the attribute of the interior of the object and one corresponding to the attribute of the region outside of the object~~of attribute double~~.

[0047] As an initial condition, a cell is considered a

space fluid cell (Euler mesh) fixed in all space (world);~~,~~ but, for a solid, the cell~~it~~ is considered a shift deformation cell (Lagrange mesh) which can freely shift and deform in each simulation. One simulation result is retrieved into V-CAD and incorporated into the static world. At this time, boundary information can be used~~is to be able~~ to reset resolution and the like. For the purpose of re-dividing/thinning out ~~of~~ object cells after deformation, bi-directional mapping from orthogonal parameter space into a deformed hexahedoron is prepared for an object cell that~~which~~ does not depend on a coordinate system. Then, ~~and~~ an up-and-down shift (i.e., a vertical shift) in the hierarchy is performed in the parameter space (i.e., an orthogonal Octree space), followed by~~then~~ re-mapping~~ being performed~~. Also, during reading input, it is necessary to correlate the simulation result with a space cell (i.e., indexing in space). In this way~~Therefore~~, a double data structure ~~which~~ containing~~s~~ a Lagr~~l~~ange mesh in a Euler mesh is provided.

[0048] Further, the physical property values of each cell can be broadly classified into two groups of values: (1)~~of~~ constant values, given initially and not changed during simulation, and (2) variable values that may change based on the results of simulation.

[0049] Among ~~the~~ examples of ~~the~~ constant values are:~~,~~ material properties (i.e., stiffness coefficient, ~~(~~Young's modulus, yield value);~~,~~ the N value (i.e., the order of

elongation in plastic deformation);~~,~~ tensile strength;~~,~~ Poisson's ratio (i.e., shearing strength);~~,~~ temperature;~~,~~ maching speed;~~),~~ friction properties (such as the characteristics of anti-friction, viscosity, shearing friction coefficient, and Coulomb friction);~~,~~ maching (boundary) condition (i.e., shift vector of tools, cooling speed).

[0050] Among ~~the~~ examples of ~~the~~ variable values are:~~,~~ for each cell, stress (i.e., symmetrical tensile amount having ~~(~~6 variables)~~,~~ and distortion (i.e., symmetrical tensile amount having ~~(~~6 variables~~)~~) and the like;~~,~~ ~~and~~ flow rate;~~,~~ pressure;~~,~~ temperature;~~,~~ and the like. In the simulation process~~ of simulation~~, when ~~there occurs~~ a difference in variable values occurs that is larger than an allowable pre-designated value ~~pre-designated~~ between adjacent internal cells, re-division is automatically performed according to the above described Octree division method until the difference decreases and falls within the allowable pre-designated value.

~~(~~Method of automatically determining resolution~~)~~

[0051] With regards~~spect~~ to automatic determination of resolution, in addition to the method based ~~on~~ constraints arising from shapes and the disparity in physical properties between adjacent cells as already described, there are constraints determined by the~~from~~ memory size and computing time required for processing, and constraints arising from~~due~~

~~to~~ pre-designated absolute accuracy settings. For example, t~~T~~he pre-designated absolute accuracy may be constrained so that~~means, for example,~~ when the cell width is 1m, further Octree division is stopped. When any one of all these above listed constraints is satisfied, the Octree division of space is stopped. This condition can provide representation having necessary and minimal resolution, thereby~~us~~ making implementation more practical~~realistic~~.

~~(~~Method of making full use of V-CAD data~~)~~

[0052] FIG. 6 schematically shows the relationship between V-CAD and V-CAD data in accordance with~~according to~~ the present invention to~~and~~ the V-interface, S-CAD, A-CAM, D-fab~~v~~ric~~v~~ation, and C-simulation.

[0053] The method of storing substantial data integrating shape and physical properties in accordance with~~according to~~ the present invention is used for representing input, output, and intermediate analysis/simulation data~~of analysis/simulation~~, such as structure analysis of solids, large-deformation analysis (i.e., rigid plasticity and elastic plasticity analysis), heat and fluid analysis, flow analysis in C-simulation etc., in addition to shape definition, modification, display, hold, study, and evaluation of ~~in the~~ design based on S-CAD and the like. Furthermore, the method of storing substantial data integrating shape and physical properties in accordance with the present invention ~~it~~ can also be ~~also~~ used for generation,

analysis, visualization, comparison and evaluation of data for removal processing, addition processing, deformation processing in A-CAM and D-fab~~v~~ric~~v~~ation, and measurement of the surface and interior of an object, data creation for instrumentation, hold of results, display, various analyses, and comparison and analysis with processed data. There are two kinds of display methods for displaying processed data in accordance with the present invention:~~of~~ surface rendering and volume rendering.

[0054] Table 1 compiles characteristics~~is for~~ comparing V-CAD in accordance with~~according to~~ the present invention with S-CAD. From T~~this t~~able 1, it can be seen that V-CAD in accordance with~~according to~~ the present invention is superior to S-CAD in many respects.

Table 1

	Adaptability to Simulation	Adaptability to Machining	Stability of Data	Controllability	Accuracy	Distributability
S-CAD system	X (acceptance of mesh gene ration time information: X)	Δ (sending and receiving data: X, geometric information only)	X (weak in conversion)	Δ (skill required)	Δ (time required)	O
V-CAD system	O (built in)	O	O (repairable due to multiple nature)	Δ (challenge to development)	O (multiple resolution)	Differentiation activation

~~Table 1~~

	~~adaptability to simulation~~	~~adaptability to machining~~	~~stability ofd ata~~	~~controllability~~	~~accuracy~~	~~distibutability~~
~~S-CAD system~~	~~×~~ ~~(acceptance of mesh generation time information: ×)~~	~~△~~ ~~(sending and receiving of data : ×, only geometric information)~~	~~×~~ ~~(weak in conversion)~~	~~△~~ ~~(required skill)~~	~~△~~ ~~(required time)~~	~~○~~
~~V-CAD system~~	~~○~~ ~~(built in)~~	~~○~~	~~○~~ ~~(repairable due to multiple nature)~~	~~△~~ ~~(challenge to development)~~	~~○~~ ~~(multiple resolution)~~	~~differentiation activation~~

[0055] FIGs. 7A and 7B are ~~the same~~ two dimensional schematic diagrams such as shown in FIG. 4, and provides a comparison~~which shows the comparison of~~ the division method according to the present invention (i.e., the modified Octree method) with the conventional Octree. FIG. 7A illustrates a conventional~~shows usual~~ Octree, and FIG. 7B shows an example of modified Octree performed in accordance with~~according to~~ the present invention. This comparative example demonstrates~~shows~~ the case of division of a thin board (i.e., the portion with scattered dots in FIGs. 7A and 7B), which is a hard object for a space division method, such as conventional Octree, to deal with.

[0056] From these FIGs. 7A and 7B, it can be appreciated~~seen~~ that the modified Octree, according to the present invention, requires less division than the conventional~~usual~~ Octree, because modified Octree~~it~~ uses the cut point-based reconstruction of a surface.

[0057] According to the method of storing substantial data integrating shape and physical properties in accordance with~~according to~~ the present invention, by using V-CAD and V-CAD data, the integration of CAD and simulation can be utilized~~achieved~~ as a tool for design. Also, the present method of storing substantial data integrating shape and physical properties ~~it~~ can be integrated with CAM, which~~that~~ is a tool for processing. Furthermore, the present method of

storing substantial data integrating shape and physical properties ~~it~~ has usefulness and novelty as a modeling technique for more generally representing a~~n~~ real world object~~ of real world~~ in a computer. In this way,~~, by which~~ shape and physical properties, each conventionally separated ~~conventionally~~, can be integrated and thus the real world "object" can be represented as an "object" in terms of ~~(~~substantial data~~)"~~. Thus, the storage method of the present invention, as fully described above, has the potential for use in development that leads to integration of artifact and natural matter.

[0058] Although solid CAD is mainstreaming as~~as~~ a tool for design ~~is going mainstream~~ as described above, volume CAD may now provide~~is to be~~ the basis for design in next generation in view of the presently described method of storing substantial data integrating shape and physical properties. Volume CAD perfectly integrates CAD and simulation, enabling more efficient management of each process of design, analysis, machining, assembly, test, and the like utilizing~~under~~ the same data. Also, it becomes~~is~~ possible to incorporate natural matter, such as a human body, into design and analysis, as well as artifact, thereby~~us~~ treating the natural matter "as is."

[0059] Therefore, the method of storing substantial data integrating shape and physical properties, in accordance

with~~according to~~ the present invention, can store the substantial data integrating shape and physical properties in a small storage capacity. Consequently~~Thereby~~, the ~~it is possible to~~ management of shape, structure, physical-property information, and history of matter, becomes possible in a unified way. Likewise, the~~, and to~~ management of data associated with a series of processes from design to work, assembly, test, evaluation, and the like processes, becomes possible while using~~nder~~ the same data, which~~thus~~ enables~~ing~~ the integration of CAD and simulation. Therefore, the storage method according to the present invention plainly~~described above~~ has superior advantages.

[0059] Further, it is evident~~natural~~ that the present invention is not limited to the specific implementation forms and embodiments as described above, but various modifications can be made without departing from the subject matter of the present invention. For example, the removable electrode according to the present invention is not limited to those used~~that~~ for electrolytic dressing grinding, such as shown in FIG. 1. In other words, the present invention~~ and~~ can be applied to any electrode for electrolytic dressing grinding.